little. Navigation above Dam No. 8 has been practically suspended for several months. Recently, the upper pools were drawn off enough to fill the pools from Lock 10 to Lock 8 in order to permit the delivery of concrete materials to the site of a bridge under construction at Boonesboro. Pictures attached show conditions at some of the dams. (See halftones in inset.)

The Kentucky River is formed by the junction of its three forks at Beattyville. At its lowest, the North Fork discharged only about 4 cubic feet per second; the South Fork 2 feet; and the Middle Fork nothing at all. Total drainage area, 2, 500 square miles.

A number of cities in central Kentucky are passing through water famine in their municipal supplies. Most of them depend upon catchment reservoirs on small streams well up on the divide. Lexington, a city of 50,000, is frantically laying water main to draw water from Kentucky River. It was estimated that its local supply would be exhausted about December 1, and that Kentucky River water would be pumped into the reservoirs November 26. Shelbyville has been hauling water by train from Louisville for several months. Paris was rationed to two hours a day until a citizen who had a private reservoir upstream, drained his reservoir into the municipal supply. Richmond was asking for elevations of Kentucky River pools with a view to laying a pipe line to the river. I have not heard what became of the plan, but do know they were in dire need of water. A manufacturing plant at Lawrenceburg has been hauling water from the river in motor tanks, but has been given a permit to pump water from the river to its plant. The city of Lawrenceburg is on water ration.

Smaller towns and villages and individuals have been hauling water from the river for months. Many of the farmers were compelled to dispose of their livestock at a sacrifice for lack of stock water.

SQUALL LINES IN NEW MEXICO

By CLEVE HALLENBECK

[Weather Bureau Office, Roswell, N. Mex.]

The "squall line" as it is observed in the eastern half of the United States is unknown in the elevated regions of the Southwest, and probably in the rest of the western highlands also. The typical squall-line barometric depression rarely forms over the mountainous West, and when it invades this region it soon disappears. This probably is due to the topography. A cold front of any considerable breadth is speedily broken up into isolated streams or so thoroughly mixed with the warmer air that it loses its identity as a cold front.

Figure 1 will give some idea of the effect of the mountain barriers upon the integrity or continuity of a southward flow of cold air. Contour intervals are shown at 5,000, 7,000, and 10,000 feet. The cold front, which over a plains region would be comparatively unbroken, is here split up into innumerable streams, moving in different directions and at different rates of speed. These streams are further divided, by minor topographic features not shown on the map. Were the general movement from the northwest instead of the north, an entirely different set of "air streams" would result, and still another if from the west. At Roswell the pioneer stream of cold air may approach through either of two broad gaps in the mountains to the west or through the still broader general depression to the northwest. Were wind directions recorded to 32 points of the compass, the directions W. 20° S., W. 10° N., and NW. would greatly preponderate in the westerly directions, each of these three directions pointing to gaps in the mountain barriers.

When the southward flow is from east of the Rocky Mountains, it constitutes an entirely different stream of air, indicating that those mountains constitute an effective barrier clear up through Colorado. It is much damper and colder than the southward flow, west of the Rockies, that is produced by the same barometric gradient. Of this we shall have more to say presently.

Whether the cold stream is shallow or deep makes little difference so far as the effect of topographic barriers is concerned. But from observations of the movements of the lower clouds, including low stratus, it appears that the *front* of the advancing cold air is quite shallow and is governed in its direction, from bottom to top, by the topography, much as an inundation of water, 100 to 1,000 meters deep, would be. Its depth gradually increases until, after 6 to 12 hours, the mountain ridges are, so to speak, submerged. That portion of the movement above the level of the mountain barriers probably is little influenced thereby, but the lower portions of the advancing cold air continue to be largely governed by the topography. These conclusions are borne out by observations of the movements of clouds. Ordinarily, the underrunning stream reaches the level of stratus clouds within 6 hours and the level of strato-cumuli within 12 hours. Sometimes, however, it does not reach the level of the strato-cumuli at all.

Each of the isolated streams shown in Figure 1 may produce thunderstorms, and usually does so when there has been an importation of relatively moist air into the region. As a rule, east of the Continental Divide moisture can be brought in only from the Gulf of Mexico, while over most of Arizona it can come only from the Pacific Ocean. In the highlands embracing western New Mexico and extreme eastern Arizona, moisture may be imported from either direction.

A peculiar squall condition usually is observed in eastern New Mexico in connection with a pressure system similar to that shown in Figure 2. This is the movement of a stream of relatively cold air—apparently a straying portion of the counterflow west of the barometric trough—moving from the Northwest, as shown in the chart. It produces thunderstorms over the low plateaus between the Colorado-San Juan Valleys and the Grande Valley, and also between the valleys of the Grande and the Pecos. These two plateau regions are highlands as compared with the river valleys, but lowlands as compared with the mountain walls on each side. Such storms occur when the pressure distribution is approximately as shown on the chart; in fact, this chart is a composite of 18 pressure systems of the type illustrated, each of which produced thunderstorms on the uplands between the Pecos and Grande Valleys. These storms often form along a general front 50 to 150 miles wide, and usually deliver copious precipitation at elevations of 6,000 to 7,000 feet. Hail and violent winds may accompany them. The underrunning current from the Northwest may persist 6 to 12 hours, and is not a transient wind belonging wholly to the thunderstorm circulation.

Thereafter there is a return to fair weather unless the pressure distribution remains practically unchanged. Normally, the northern center of depression moves

Upper.—North Fork Kentucky River below Beattyville. Discharge, about 4 cubic feet per second
Lower.—Middle Fork Kentucky River at Beattyville. Discharge, zero

Kentucky River above Beattyville; drainage area, 1,654 square miles. Discharge, 22 cubic feet per second

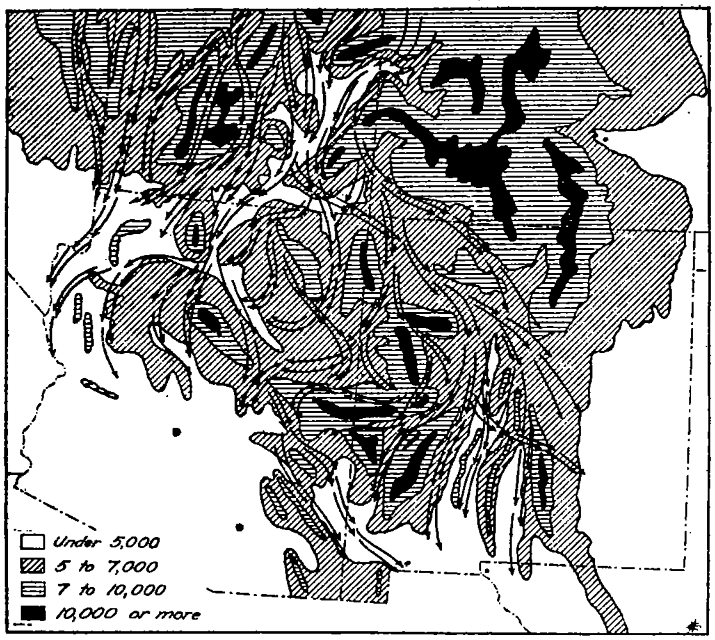

FIGURE 1.—Influence of mountain topography of New Mexico in breaking up and deflecting an advancing stream of relatively cold and dense air. Solid black, elevation of land 10,000 feet or higher; horizontally shaded, 7,000 to 10,000 feet; vertical shading, 5,000 to 7,000; unshaded, below 5,000 feet

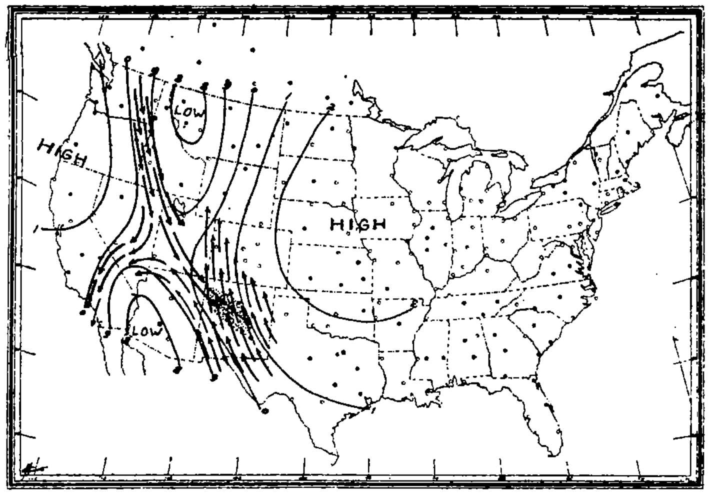

FIGURE 2

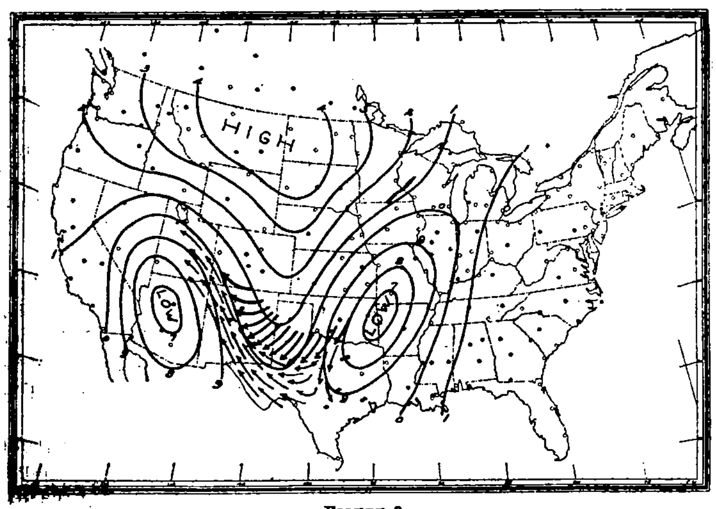

FIGURE 3

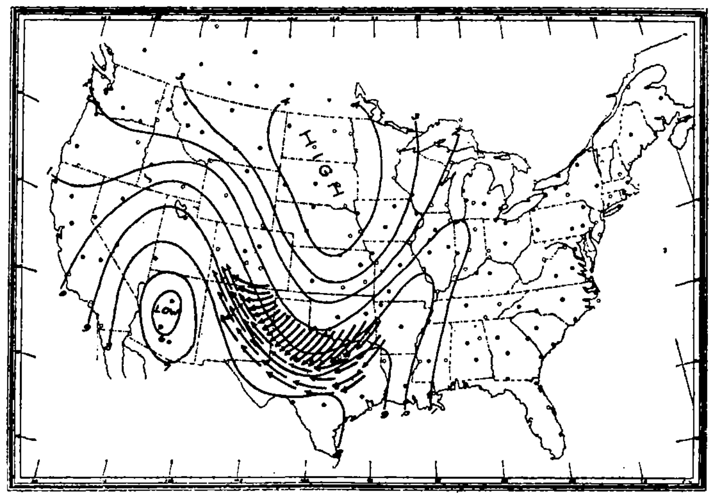

FIGURE 4

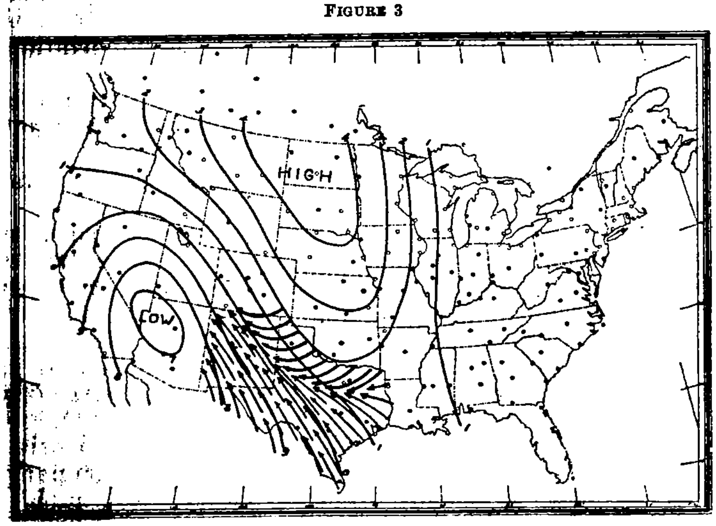

FIGURE 5

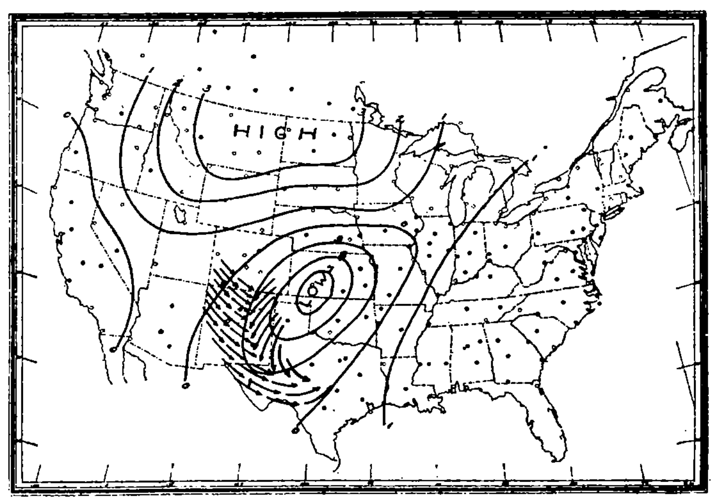

FIGURE 6

Figures 2-6.—Idealized charts of pressure and wind distribution eastward, while the southern center remains about stationary. It is a pressure distribution characteristic of the summer months, but occasionally occurring at other times of the year. It is important because the region in which it most frequently produces thunderstorms lies directly across the transcontinental air lanes.

We have remarked that the typical squall line, advancing eastward on a comparatively intact front, is unknown in this region. But eastern New Mexico and western Texas have their own type of squall line, which attends a pressure distribution quite different from the elongated, V-shaped trough known to the eastern United States.

Figures 3, 4, and 5 show the pressure systems favorable to the advance of an unbroken cold front over the area mentioned. It will be observed that the three differ principally in the location and development of the eastern center of depression. In Figure 3 it is well developed, while in No. 5 it amounts to no more than a southeastward elongation of the western depression. Nos. 3 and 4 are characteristic of the colder half of the year. No. 5, while it may occur summer or winter, is perhaps more frequent in the latter than in the former season. None of the three, however, can be said to be of frequent occurrence.

In each case, the cold air advances from a northeasterly direction. It is nearly always attended by energetic squall-line storms in the spring and fall; and while not usually attended by thunderstorms in winter, it is responsible for all the winter thunderstorms that the present writer has observed in New Mexico. These may display a turbulence and a rapidity of movement rarely exhibited by summer storms.

The cold front is most marked and of most frequent occurrence, attending a pressure distribution similar to that shown in Figure 3. Both the squall-line phenomena and the frequency of these phenomena decrease as we pass from 3 to 5; with the latter there usually is no defined cold front. However, these are only general statements; vigorous squall conditions *have* occurred with type 5, and there have been instances where type 3 resulted in nothing more than a gradual fall in temperature, unattended by cloudiness.

In this connection, we may remark that it has been our observation that the air at the lower cloud level moves approximately parallel to the surface isobars—when it does not move in some other direction. Theoretically it should always do so, and it probably does so move where the gradient is the cause and the movement the result. In southeastern New Mexico a widespread flow at the lower cloud level often is observed moving normal to the surface isobars, and sometimes directly opposite to the "gradient" direction, and persisting for 12 to 24 hours.

Often, with a pressure distribution similar to that shown in Figure 5, a cloud movement from the north or northeast sets in and persists for a whole day and night. This also sometimes occurs with pressure types 3 and 4.

The type of cold front shown on these three charts presents a baffling situation to the local forecaster, and possibly to the district forecaster as well. Its movement seems to depend upon the relative strength, so to speak, of the HIGH and the western LOW. With the HIGH increasing in energy and the LOW becoming weak, the cold front may advance with a speed unforeseen by the forecaster. But with the LOW developing more energy, and the HIGH becoming sluggish or moving eastward, the cold may be held stationary or may even retreat. Sometimes it is thus checked and does not reach New Mexico at all, and on one occasion, in the spring of 1923, it actually was within sight of the Roswell Weather Bureau station during most of an afternoon, but never arrived. And since the cold front is attended by a large fall in temperature in winter, and usually by precipitation at all seasons, it can be understood what havoc unexpected behavior on its part can play with a forecast.

If as the writer maintains, the pressure distribution over the Southwest at such times is the result, rather than the cause, of the air movement, then in this case we have two opposing currents, and the zone of conflict between them may advance or recede, depending upon their relative strength or persistence. Owing to the dearth of first-order observing stations in the region, the forecaster unfortunately can not always foresee changes in the energy of the two opposing streams of air.

However, since most of the air traffic over this region, at the present time, is along southwest-to-northeast routes, the air lanes are approximately normal to the position of the cold front, and it should not be a very difficult matter to correctly advise the aviator of the presence of a belt of turbulence lying across his path, although to advise him just where he will encounter the dangerous weather is a different matter. The cold front usually is attended by much turbulence, even when there is little or no cloudiness, the absence of cloudiness being due to very low atmospheric humidity.

It may happen, in the case of a pressure distribution like that shown in Figure 3, where the cold stream of air is a comparatively narrow tongue or wedge, that the aviator will cross two squall lines in the course of an ordinary day's flight, the one on the west and the other on the east boundary of the cold air, although the meager data in our possession indicate that the western front is the more turbulent and dangerous of the two.

We have said that the pressure system shown in Figure 5 occurs in the summer as well as in the colder months, but, while it then may produce thunderstorms, these, so far as we have observed, never display much turmoil. On the contrary, they are remarkably well-behaved, for thunderstorms. These have previously been discussed by the writer (M. W. R., May, 1917).

Cold fronts advancing southwestward over eastern New Mexico remain practically intact until they reach the mountain barriers between the Pecos and Grande Valleys. There they are broken up into isolated streams, and they reach the Grande Valley only as importations of cold air exhibiting little or no turbulence.

There is one other pressure system to be mentioned as producing cold-front conditions, or something analogous thereto, in eastern New Mexico. This is shown in our final figure, No. 6. A barometric depression moving eastward across northern New Mexico or Colorado is attended, east of the mountains in New Mexico, by westerly and northwesterly winds that, while a part of the colder countercurrent, nevertheless are relatively warm and quite dry. It is exceedingly rare that any considerable fall of temperature comes in on such a wind. But after the center of depression has reached western Kansas or northwestern Texas, there is a comparatively rapid shift of the wind from northwest to northeast—often an abrupt change—with a sudden rise in velocity, a rapid fall in temperature, and frequently an accompanying blanket of clouds. The humidity rises rapidly with the change in wind, and sometimes there is precipitation. At times, too, there are thunderstorms and squall-line turbulence, but only when the center of depression has passed south of Colorado. This type of pressure distribution occurs more frequently in spring than in any other season of the year, but no season is free from it.

Other types of pressure distribution produce thunderstorms in this region, but only the types illustrated produce squall-line storms in that portion of New Mexico lying east of the continental divide.

The cold front, with its squall-line phenomena, as known in the eastern half of the United States, can not take shape in the mountainous region of the Southwest, where the front of an advancing cold current is broken up by mountain barriers into isolated streams that produce thunderstorms, only when there has been a previous importation of relatively moist air.

But a vigorous southward flow of cold air over the plains States reaches New Mexico with a well-defined cold front moving southwestward, along which decided squall-line phenomena often occurs.

The mountain ranges of central New Mexico mark the western limit of this type of squall line, so that over the larger portion of New Mexico importations of cold air are only in the form of narrow streams following the topographic depressions.

LATE TERTIARY CLIMATIC CHANGES IN OREGON

By EDWIN T. HODGE, Professor of Geology [University of Oregon]

Evidence is presented in this paper of five climatic changes in Oregon beginning in late Pliocene time and extending into Recent time. These changes have ranged between epochs characterized by extensive glaciation with a large supply of precipitation and epochs of limited glaciation and a comparatively small precipitation. The evidence presented in support of these conclusions may be found in the glacial and stream work on the uplands of the Cascade Mountains; in the valley profiles and deposits of streams on the west side of the Cascade Mountains and Willamette Valley; in coastal deposits; in widespread formations adjacent to the John Day, Deschutes, and Columbia Rivers; in these same canyons and their deposits; and in the silts and sands of Fossil Lake.

Each of these areas show five stages, but in only a few cases can a given stage be definitely shown to be identical with a stage of another area. The writer approves and presents reasons for the suggestion that the few stages of each area are in parallel series.

EAST SIDE OF CASCADE MOUNTAINS

Evidence of Stage II is to be found in The Dalles formation. The Dalles formation lies east of the Cascade Mountains and is of great importance in this study. (Fig. 1.) It is found east of the east fork of Hood River and extends in places to the Deschutes River. Small patches occur on the north side of the Columbia River east of the Klickitat River. South of Columbia River and beginning east of Mosier it occurs in great tongues lying in structural or erosional depressions. North of Fifteen Mile Creek and west of Deschutes River it almost covers the entire surface. Another great area lies west of the Deschutes River between Tygh Ridge and Mutton Mountains.

The Dalles formation is about 600 feet thick and is composed of well-bedded sediments and lavas. The sediments consist of water-worked glacial till, pumice, sand, gravels, and silts. The gravels and bowlders embedded in a volcanic sand show torrential cross-bedding. The andesitic lavas seal the other beds between and form a protective cover over them.

These beds lie nearly flat and fill all erosional and structural depressions. They completely obliterate the topography of the lowlands east of the Cascade Mountains and west of the Deschutes River. These structural characteristics of the beds suggests a Recent age for these deposits, but they must be older for they contain many glacial erratics.

For instance, near the city of The Dalles subangular, striated glacial erratics are abundant. They range in size from 15 feet in diameter to several inches in diameter. Associated with these are many subangular fragments which show no striation or polishing, but strongly suggest glacial origin. Some of these occur in a gray fluffy silt, wherein they have a most heterogeneous arrangement and look like true glacial deposits.

The larger fragments in The Dalles formation, which make up over 50 per cent of it, are clearly referable to Mount Hood. Furthermore, the materials can be traced almost to Mount Hood but not the entire distance. The interruption that defeats the complete tie is the east branch of Hood River Valley.

The Dalles formation, though it contains glacial erratics, is made up essentially of torrential materials. At the time this is written it is not certain whether glaciers extended as far eastward as The Dalles. It is quite likely that glaciers did reach 30 miles eastward from (say) Mount Hood, as shown by other morainal deposits mentioned below. The Dalles formation may be, therefore, either an outwash plain deposit, given off in front of glaciers on the Cascade Mountains, or aggradational deposits formed by streams active during a nonglacial stage following a glacial stage. For the purpose of the theory presented here it does not matter which origin is correct; the one essential fact is certain that an early glacial stage existed.

The glaciers that produced The Dalles formation, if they did not reach 30 miles eastward, at least extended far beyond the east fork of Hood River.

One of the most striking features regarding the Pleistocene, as of the present, is the evidence of intense glaciation on the east side of the Cascade Plateau. The presence of the glaciers at the present time is determined by the fact that the moist winds striking these mountains come from the west. During the ice age the prevailing winds were undoubtedly from the same direction, and a controlling factor in that glaciation was the superior altitude of the crest of the Cascade Mountains. The elevated crest robbed the winds of their moisture. Much of the snow falling from the chilled winds rising over the Cascade Range must have been carried by these same winds over the crest.

Snow, unlike water, falls to the ground as a light fluffy solid and for this reason may be picked up by the winds and drifted over the crest of divides. Thus, for instance along the peak of a house we find that the heaviest snow is on the leeward side of the roof. On a mountain, in a